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THE DETECTABILITY FUNCTION FOR THREE BAR TARGETS[1]

When the performance of a photographic optical system is described by its Modulation Transfer Function, its actual performance on real scenes cannot be predicted unless some form of detectability function is available for the type of informational material in the scene. Since the three bar target is a frequently used form of evaluation scene, a detectability function for this target is presented here. It has been our practice[2] to include the film modulation transfer function[3] in the system MTF. The method of measurement of the MTF for the film is designed to free the result of the effects of processing and grain. These both have strong influence on the detectability of the three bar target test object, however, and so are included in the detectability function.

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The function presented here has been developed by [redacted] from data by D. E. Macdonald[4], G. C. Brock[5], and observations at Perkin-Elmer by

STATINTL [redacted] These results must be considered as preliminary.

For large areas, well resolved, the detectability is limited by the modulation or contrast detectability of the eye of the observer. A useful value based on measurements of the capability of the eye[6] is between 0.03 and 0.04 modulation. This limit of detectability exists in the light reaching the eye. Thus, in order to determine the limit in the exposure, the above limit is reduced by the γ of the photographic material. As the detail becomes finer, the grain of the photographic material interferes with the ability of the observer to "see" the detail and thus the modulation of the image must be greater for the three bar target to be resolved. A relation of the form

$$M_i = T(k)M_o = \frac{C\,\sigma(D)}{\gamma} \qquad k = ak$$

where:

M_i = Modulation produced by the system for a three bar target to be resolved at optimum exposure.

$T(k)$ = Modulation transfer function of the system

M_o = Modulation of the target in the scene

$\sigma(D)$ = Granularity value obtained with 24 micron scanning aperture

γ = Gamma of processed film at average density of target

k = Spatial frequency in cycles/mm for just resolved three bar target

C = A constant to be determined from the observations.

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1 MIL-STD-150A, "Military Standard Photographic Lenses", U. S. Government Printing Office; Washington 25, D.C. (Revised 8 June 1961)

2 "The Practical Application of Modulation Transfer Functions", Perkin-Elmer Corporation; March 6, 1963

3 Lamberts, R. L., J.OPT.SOC.AM. 49, 425 (1959)

4 Macdonald, D. E., (Table I) JOSA 46, 715 (1956)

5 Brock, G. C., Itek, [illegible] April 4, 1963

6 Selwyn, E.W.H., PRO[illegible]

gives a useful approximation to the modulation required to resolve a three bar target.

The value of the constant C seems to be somewhat dependent on the class of film. For "coarse grained" films such as EK 4401 and 8403, the best value is 0.04 while recent observations on 4400, 4404 and SO-243 of the "fine grain" types, 0.03 gives more consistent results. The relation above covers the portion of the detectability function when graininess limits the detectability. The transition region has not been explored in any detail and is shown as dotted in Figure 1.

As an example of how this function is used, consider a system whose overall transfer function is shown in Figure 2. Let us consider two films, EK 4404, a high definition, slow material processed to a γ of 2.0 and whose granularity, $\sigma(D)$, is 0.023; and 8401, a faster material with a γ of 1.6 and a $\sigma(D)$ of 0.085.

Table I

EK Film Type	C	$\sigma(D)$	γ	a (mm/cycle)	k(ak=1)
4404	0.03	0.023	2.0	0.00035	2900
8401	0.04	0.085	1.6	0.0021	480

In the figure, two target contrasts are shown, one for a modulation of 1.0 and a second for 0.20. It is to be remembered that no scattering or haze effects have been included thus far so that under real conditions the contrast of the target will be reduced toward the lower value.

The fine grained material will be just beginning to be grain limited when used with this system as indicated by the detectability lines intersecting the system lines at 62 and 48 cycles/mm for the two contrasts. On the other hand, the faster material will be completely grain limited in both cases at 46 and 27 cycles/mm.

To plot the detectability curves as shown in Figure 2, Figure 1 is placed under the system curves and positioned so that ak = 1 falls under 2900 or 480 cycles/mm as computed in the table. (K = 100 may be positioned over ak = .035 and ak = .21 if this is more convenient.) For $M_o = 1.0$ the detectability curve is positioned vertically so that $M_i = 1.0$ is under $T(k) = 1.0$ and for $M_o = 0.2$ $M_i = 0.2$ is under $T(k) = 1.0$.

THE USE OF EDGE GRADIENTS FOR SYSTEM ANALYSIS

On many occasions it is desirable to arrive at a good estimate of system performance from material which does not contain images of resolution targets. The method to be described is based on a suggestion by R. V. Shack[7] and applied and developed by [redacted] for this purpose.

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The first and most important step is to provide a sensitometric exposure on the film to be evaluated. This is best done in the camera at almost the same time as the exposure. No absolute intensity calibration is required but care should be taken that the relative exposures are accurately known. A uniformly illuminated density step tablet is satisfactory if the duration of the exposure and the quality of the illumination simulate the scene exposure. The exposures may be made at different times if the interval to processing is long enough so that any time effects between exposures and processing are minimized. From this sensitometric exposure a modified form of H&D curve will be developed and the accuracy of the method depends on the accuracy of this curve.

The steps in this method, to proceed from an edge in a picture to the transfer function of the system, are as follows:

1. Select an edge in the scene which is straight for many resolution elements and is known to have a step function brightness distribution. Examples are shadows of straightedges of buildings on smooth surfaces, and the ridge of a peaked roof with different illumination on the two sides. The edge must separate two areas of uniform density which are large enough to be well resolved.

2. Trace the sensitometric steps and the edge with the same slit and settings of the microdensitometer. The slit must be long enough (and thus the edge) to give a good trace with a minimum of grain noise. The slit must be narrow enough so that its transfer function does not obscure the function of the system being evaluated. Figure 3 illustrates a typical tracing.

3. Convert the deflections of the densitometer into relative exposures by plotting deflection vs. exposure from the sensitometric images. The left side of Figure 4 is typical.

4. Draw a smooth curve through the edge trace (care at this point will be repaid later) and draw the curve of relative exposure vs. displacement.

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7 Letter R. V. Shack to [redacted], 25 May 1962

5. Measure the points on the curve and construct a table such as Table II.

6. Compute and draw the square wave modulation vs. cycles per millimeter curve. Method to be described below, but see Figure 5 for result.

7. Correct the square wave curve to a sine wave modulation transfer function.

8. Remove the transfer function of the scanning slit.

Table II

Square Wave Frequency (k)		E_A	E_B	E_C	E_D	E_E	E_F	$\overline{M}$
0.01 mm	50 c/mm	0.190	0.195	0.242	0.344	0.390	0.395	0.093
0.015	33.3	0.190	0.190	0.224	0.364	0.395	0.395	0.36
0.020	25.0	0.190	0.190	0.209	0.377	0.395	0.395	0.64
0.025	20.0	0.190	0.190	0.200	0.385	0.395	0.395	0.76
0.030	16.6	0.190	0.190	0.195	0.390	0.395	0.395	0.90

The steps above, 2 through 4, are the normal practice of photographic microphotometry and need no further description here. Step 5, however, will be discussed. Consider one pulse of a train of pulses forming a symmetrical square wave. The pulse is the difference between two step functions, one displaced by a pulse width from the other, (a) in Figure 6. If each step is considered an edge and spread out by the observed edge spread function, the result will be a wave of reduced amplitude, (b). Each solid curve corresponding to the positive pulse spread by the edge spread function must have subtracted from it its associated dotted curve for the displaced step. Note that for this case where the square waves are wide compared to the spread function, the amplitude in the image is just the difference in the heights of the spread function for two points symmetrical about the midpoint of the function and spaced the pulse width. As the pulses get narrower, frequency gets higher, and the amplitude will decrease, and at some point there will be contributions from neighboring lines and losses to neighboring spaces. The maximum exposure of the constructed image is

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$$E_{max} = (E_B - E_A) + (E_D - E_C) + (E_F - E_E)$$

while the minimum is

$$E_{min} = (E_C - E_B) + (E_E - E_D)$$

The modulation in the image due to a square wave exposure is

$$\bar{M} = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} = \frac{-E_A + 2\,(E_B - E_E) - 2\,(E_C - E_D) + E_F}{-E_A + E_F} .$$

The values of the various E's are read from the edge spread curve for a selection of separations. The separations are equal to 1/2k. The interval C-D must be centered on the curve. To accomplish this, set the center of this interval at the point of average exposure, averaged from the exposure on the two sides of the edge. Tick marks in Figure 4 show the points selected for this example and used to construct Table II. For Step 6, the formula is used to determine $\bar{M}$ and this is plotted.

The relation between the modulation of a square wave and its sine wave components is

$$\bar{M}(k) = \frac{4}{\pi}\tilde{M}(k) - \frac{4}{3\pi}\tilde{M}(3K) + \frac{4}{5\pi}\tilde{M}(5K) - - - - .$$

From the highest frequency transmitted by the system at all down to about 1/3 of that frequency, the square wave modulation differs from the sine wave modulation only by the factor $\frac{4}{\pi}$. Thus

$$\tilde{M}(k) = \frac{\pi}{4}\bar{M}(k) \qquad \frac{k_{max}}{3} \leq k \leq k_{max}$$

At lower frequencies a further correction is required

$$\tilde{M}(k) = \frac{\pi}{4}\bar{M}(k) + \frac{1}{3}\tilde{M}(3k) \qquad \frac{k_{max}}{5} \leq k \leq \frac{k_{max}}{3}$$

In these relations $\bar{M}$ is the image modulation resulting from a square wave exposure while $\tilde{M}$ is the modulation in the image from a sine wave exposure both of frequency k. Additional corrections for frequencies lower than $k_{max}/5$ can be made if desired but generally at one fifth the max resolution the transfer function is almost 1.0 in any case.

It is to be noted that this method gives the transfer function of the system without a knowledge of the actual intensities at the target, the haze in the atmosphere, or the wide angle scattering in the system. This is because the step in the scene was assumed to be as measured photometrically in the image on the film. Thus these effects are not determined by this method without additional knowledge of the target. Nevertheless in those cases where only unstandardized targets are available, the method yields considerable useful information on system performance.

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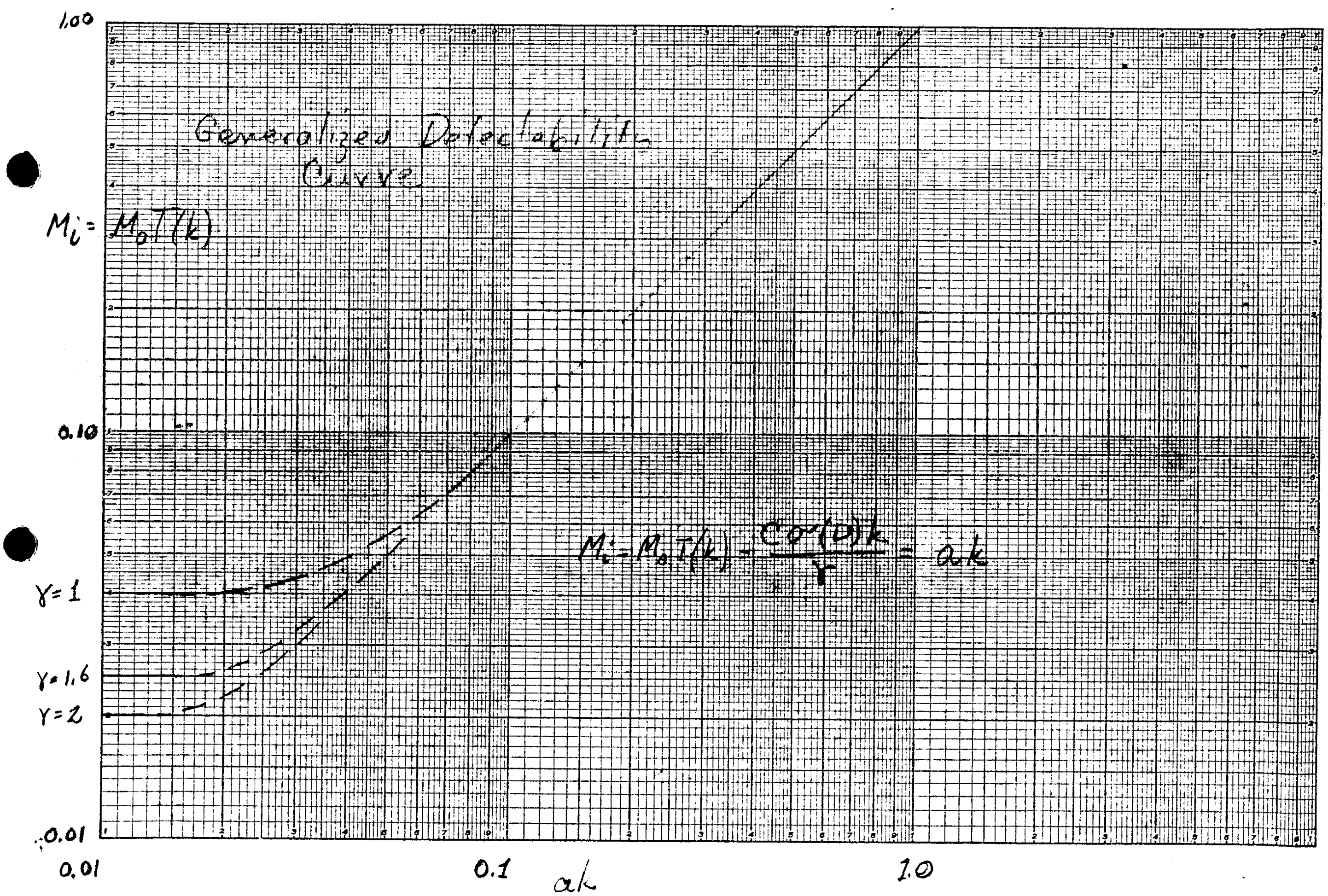

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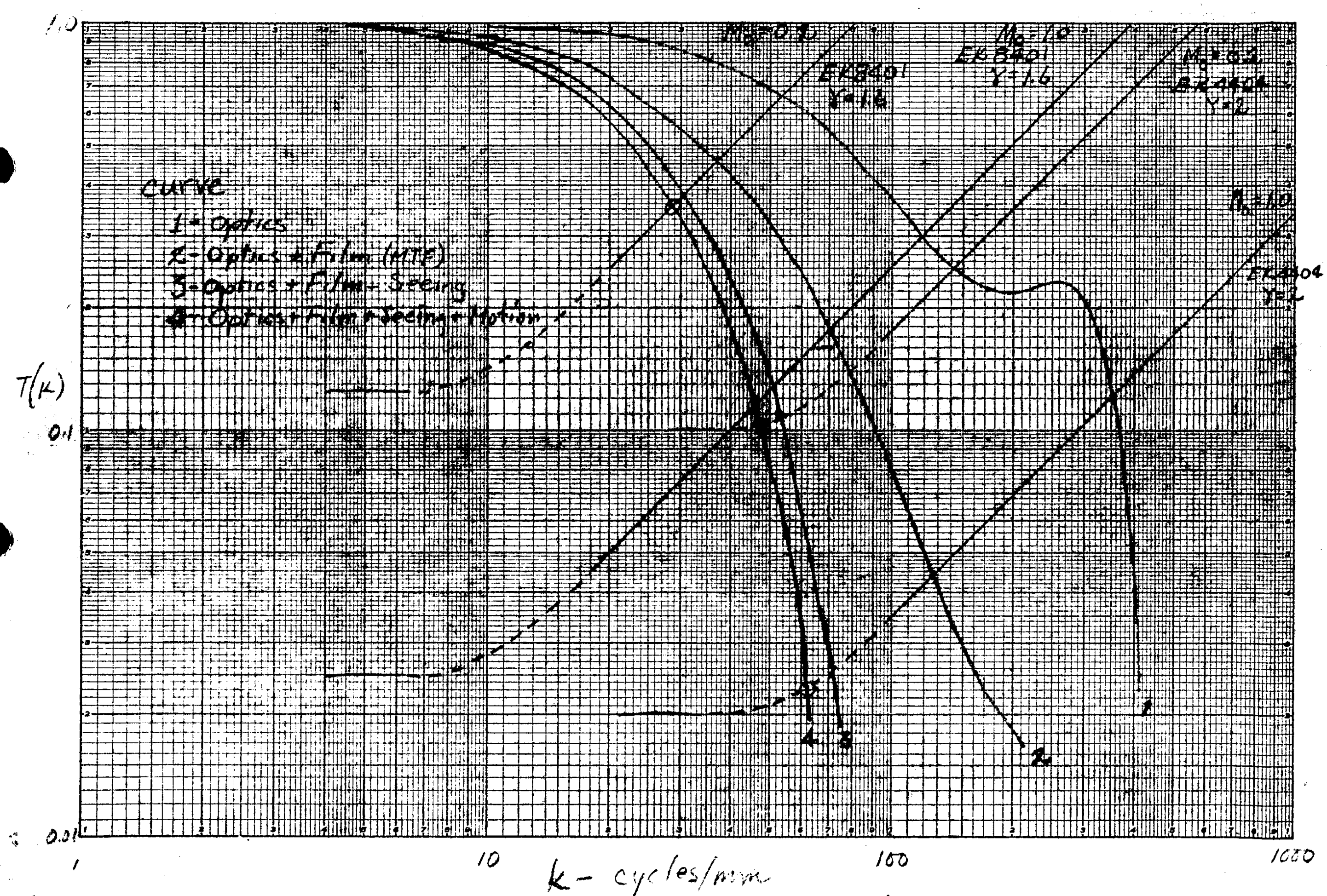
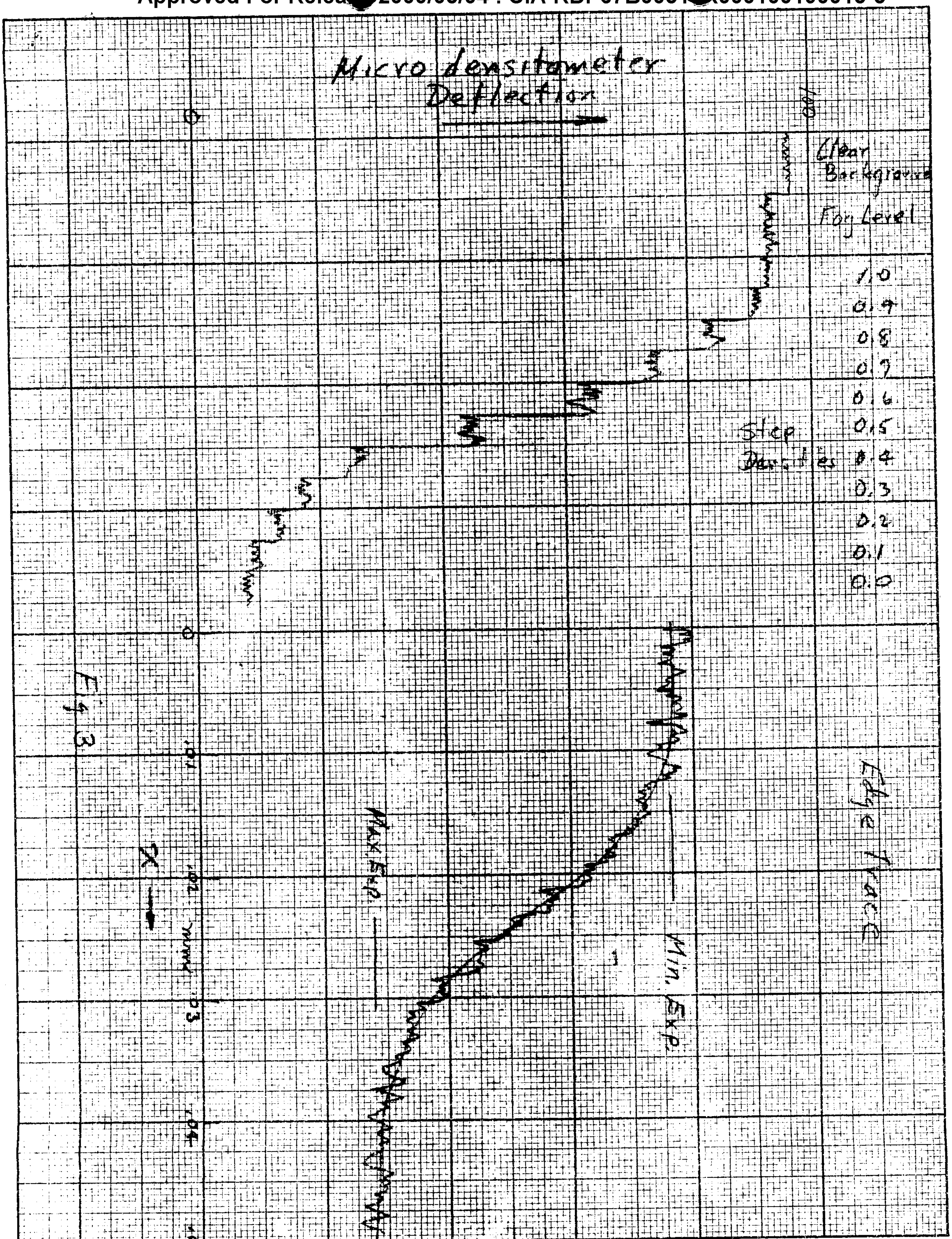


1.0
0.1
0.01
T(k)
1
10
100
1000
k - cycles/mm
Curve
1 - Optics
2 - Optics + Film (MTF)
3 - Optics + Film + Seeing
4 - Optics + Film + Seeing + Motion
EK 8401
γ = 1.6
M₀ = 1.0
EK 8401
γ = 1.6
M₀ = 1.0
EK 4404
γ = 2
EK 4404
γ = 2
1
2
3
4

Figure 8



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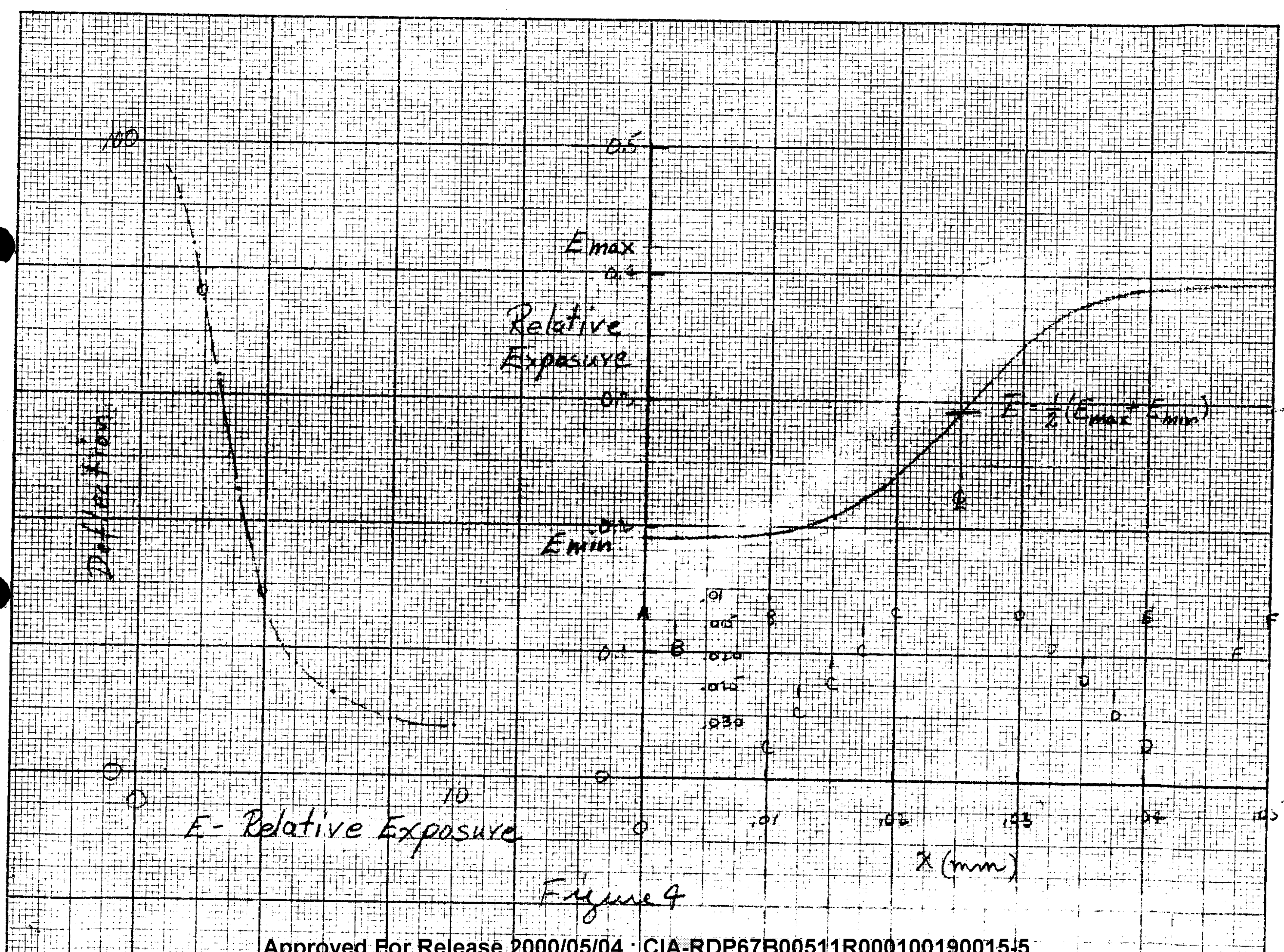

100
Deflection
10
E - Relative Exposure
Emax
0.4
0.5
Relative
Exposure
0.3
0.2
Emin
0.1
$\bar{E} = \frac{1}{2}(E_{max} + E_{min})$
.01
.005
.010
.015
.030
0
.01
.02
.03
.04
.05
X (mm)

Figure 4

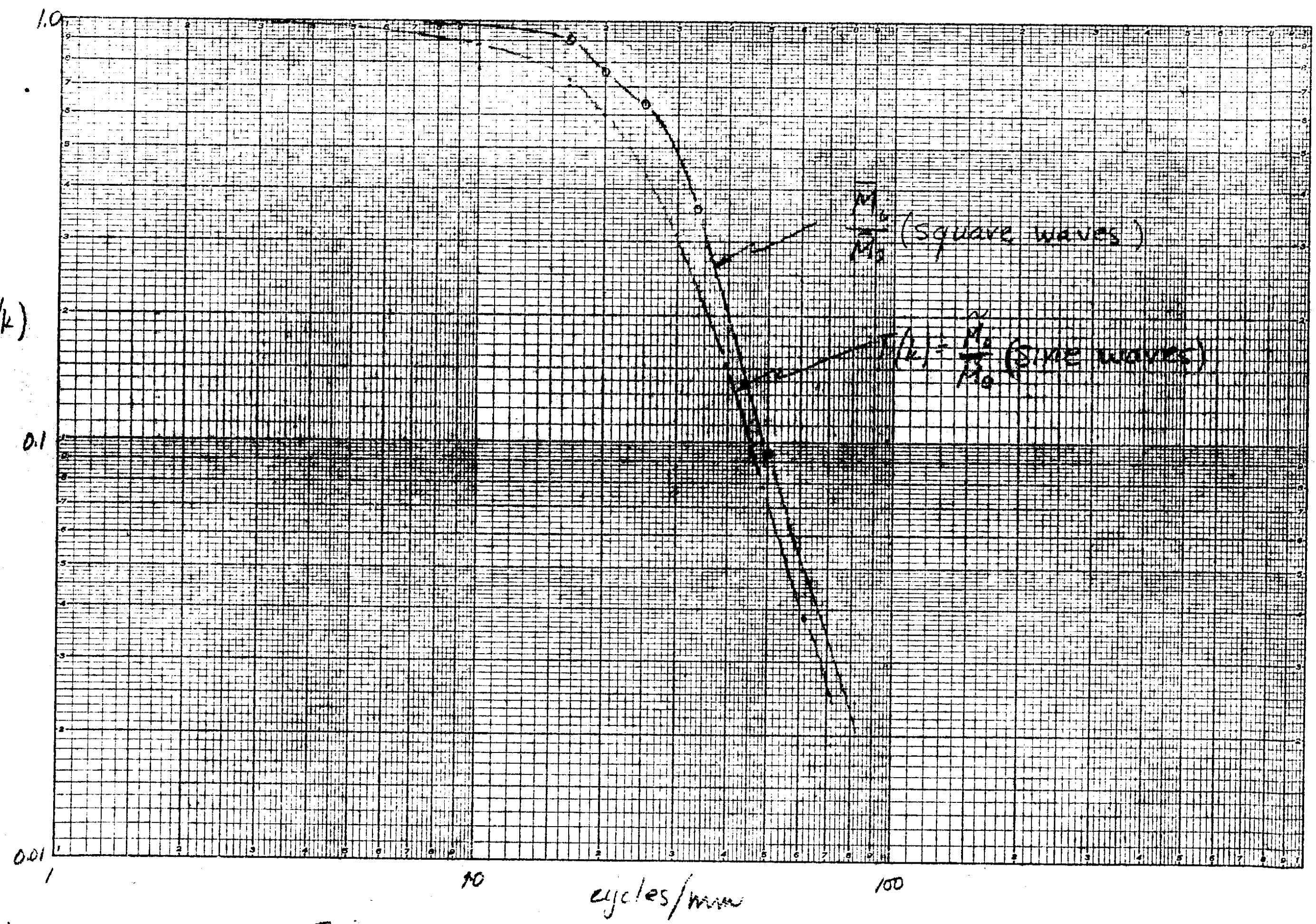
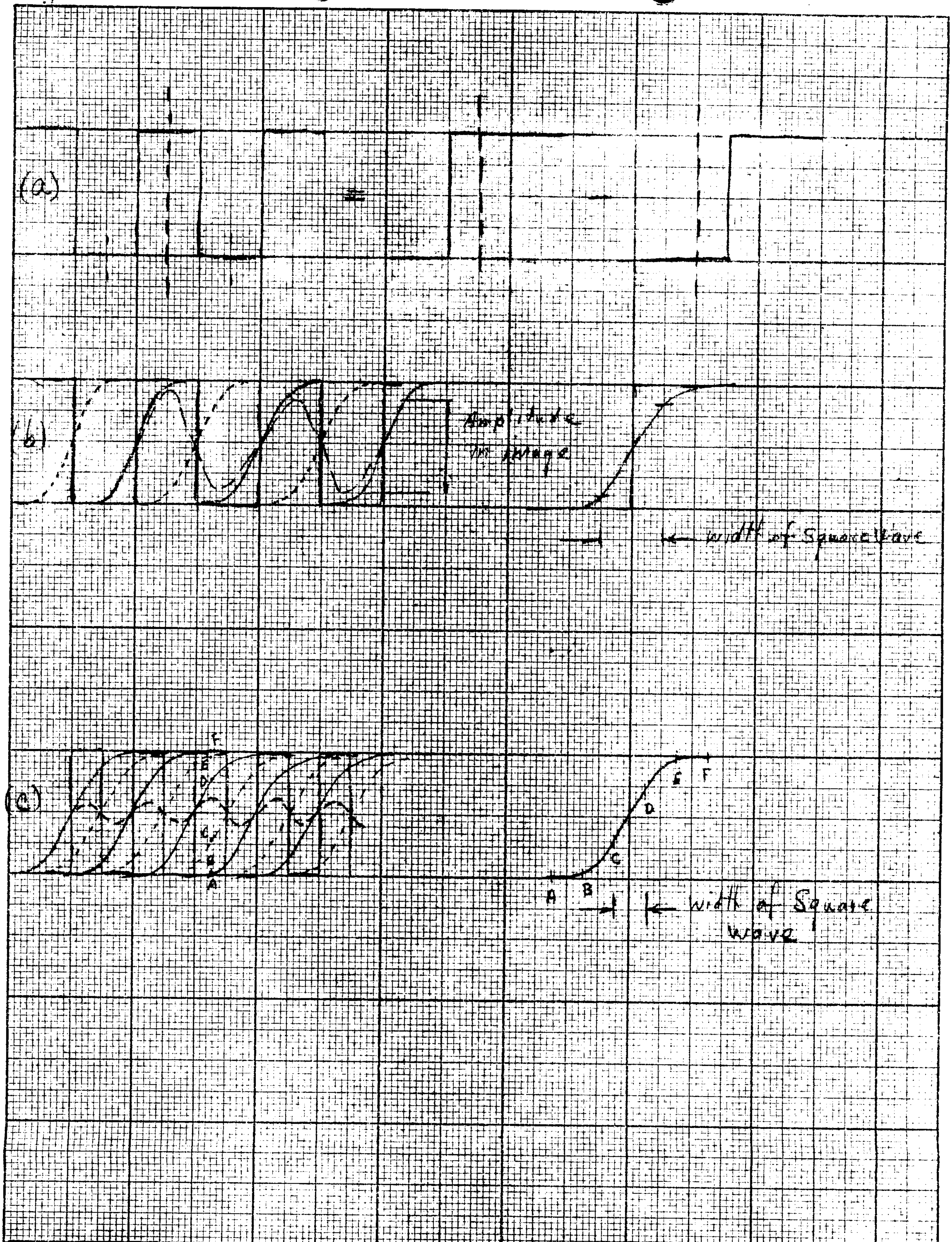

1.0
0.1
0.01
T(k)
1
10
100
cycles/mm
$\frac{\bar{M}_b}{M_a}$ (square waves)
$T(k) = \frac{\tilde{M}_b}{M_a}$ (sine waves)

Figure 5


(a)
(b)
Amplitude
in image
width of Square Wave
(c)
F
E
D
C
B
A
A
B
C
D
E
F
width of Square
wave